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CHARACTERIZATION OF THE ULTRAVIOLET PROTECTION OF COMBAT UNIFORM FABRICS

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14. ABSTRACT
Military combat uniforms are required to meet specific performance requirements against various environmental conditions, such as wind, rain, and/or cold temperatures. Ultraviolet protection is one important aspect of environmental protection for which the military currently has no set performance requirements. This report is intended to inform readers of ultraviolet testing that has been performed on four fabrics used for Battledress Uniforms (BDU) and the results of each test. The tests gave each fabric an Ultraviolet Protection Factor (UPF) which is vital in determining the effectiveness of current military fabrics in protecting the soldier against ultraviolet radiation. All of the fabrics rated highly, with the lowest rating being a UPF of 35 and the highest and most frequent rating being that of 50+. This is significant in that such ratings indicate that the current fabrics are very good or excellent protectors against harmful ultraviolet rays. The report also delves into the implications and effects of ultraviolet radiation and the growing need to implement specific standards as a means of helping to protect against sun-related diseases, such as skin cancer and photoaging and other such ramifications. As the number of military conflicts in solar-intensive climates increases, it is essential to evaluate the ultraviolet protection that the soldier is receiving.

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COMBAT UNIFORMS	FABRIC COVER	FABRICS	
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ENVIRONMENTAL CONDITIONS	PHOTOAGING	SKIN CANCER	

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TABLE OF CONTENTS

CONTENTS (Cont'd)

LIST OF TABLES

PREFACE

This report outlines the American Association of Textile Chemists and Colorists (AATCC) and American Society for Testing and Materials (ASTM) tests that were performed on four military fabrics used for Battledress Uniforms (BDU) in order to determine their levels of ultraviolet protection. New fabrics, as well as those simulated for two years of use, were tested. Each test gave the fabric an ultraviolet protection factor (UPF), which is vital in determining the effectiveness of current military fabrics in protecting the soldier against ultraviolet radiation. In addition, this report delves into the implications and effects of ultraviolet radiation and the growing need to implement specific standards as a means of helping to protect against sun-related diseases, such as skin cancer, photoaging and other such ramifications. Characteristics affecting the level of ultraviolet protection that a fabric provides are also explained.

This project was undertaken during the period January 2001 to June 2001, and funded under Program Element Number 622786 and Project Number AH98.

CHARACTERIZATION OF THE ULTRAVIOLET PROTECTION OF COMBAT UNIFORM FABRICS

INTRODUCTION

Military combat uniforms are required to meet specific performance requirements against various environmental conditions, such as wind, rain, and hot or cold temperatures. Such criteria are set to provide the soldier with environmental protection against a variety of weather conditions. Ultraviolet (UV) radiation protection is one important aspect of environmental protection for which the military currently has no set performance requirements. The American Association of Textile Chemists and Colorists (AATCC) and the American Society for Testing and Materials (ASTM) have both recently published new standards for testing and determining the ultraviolet protection factor (UPF) of textiles. This opens the door for both the military and civilians to begin testing the ultraviolet protection levels of textiles.

This report is intended to inform readers of testing that has been performed on four fabrics used for Battledress Uniforms (BDU) and the results of each test. It will also delve into the implications and effects of ultraviolet radiation and the growing need to implement specific standards as a means of helping to protect against sun-related diseases and other such ramifications. As the number of military conflicts in solar-intensive climates increases, it is essential to evaluate the ultraviolet protection that the soldier is receiving.

The International UV Testing Laboratories in Auburn, Alabama performed both the AATCC and ASTM test methods in March 2001.

This report and background research has been compiled by Kristie DiLuna a Student at the University of Rhode Island, under the direction of CaroleWinterhalter, Textile Technologist at Natick Soldier Systems Center and Martin Bide, Professor of Textile Sciences at the University of Rhode Island.

METHODS OF ANALYSIS

Two procedures were performed in determining the ultraviolet protection factors of the military textile and clothing applications. These methods are described below.

AATCC 183-1999 – Transmittance or Blocking of Erythemally Weighted Ultraviolet Radiation through Fabrics

This test uses a spectrophotometer or spectroradiometer at specific wavelengths to measure the transmission of ultraviolet radiation of new fabrics. By testing a minimum of two specimens from each textile sample, it is possible to gather precise data, including the UPF, average ultraviolet-A (UV-A) and ultraviolet-B (UV-B) transmittance, and the percent blocking for the UV-A and UV-B rays.

ASTM D 6544-00 – Standard Practice for Preparation of Textiles Prior to Ultraviolet Transmission Testing

The purpose of this procedure is to allow the determination of the ultraviolet transmission of fabrics, as they would be after approximately two years of seasonal use.

After laundering the materials forty times under specified conditions, a Water Cooled Xenon Arc Lamp with continuous light is exposed to the fabrics to simulate various levels of sunlight. For the purpose of this research, the fabrics were exposed to 100 AATCC fading units (AFU), to achieve the desired levels of use. The combination of preparation and the AATCC test allowed for the maximum transmittance of the textiles after a two- year life cycle to be determined. This procedure allows specific factors, such as stretching and laundering, to be taken into account, which may affect the overall performance of the fabrics.

ASTM D 6603 – Guidelines for Labeling UPF Fabrics

This guideline for labeling[1] requires that textiles chosen to be designated as UV protective must be labeled according to a UPF classification category. ASTM has designated three categories necessary for labeling textiles. The categories are Good UV Protection (UPF 15-24), Very Good UV Protection (UPF 25-39), and Excellent UV Protection (UPF 40-50+). Products must also include a label that indicates, "Product labeled according to ASTM D 6603." There are also optional labeling components. The first is that UPF values must be reported in increments of five and rounded down. Thus, a UPF of 34 would be reported as having a UPF of 30. If a company decides to include the percent of UV blocked by their item, then both percent UV-A and percent UV-B must be reported separately. Additionally, percentages for UV blocked may not exceed 99 percent. Five optional statements have also been selected to be used as optional labeling components. These statements include:

1. "UV protection value indicates the lowest amount of protection that can be expected during the life of the product."
2. "Product reduces exposure to harmful UV-A and UV-B rays."
3. "No textile product provides 100% protection from UV radiation."
4. "Protection offered by this garment may be lessened..."
5. "Only skin covered by the fabric is protected from sunlight exposure."

ADDITIONAL TEST METHODS

In addition to the AATCC and ASTM procedures, two methods used internationally are known to exist, but were not available during this study to perform a full analysis and comparison to the ASTM and AATCC methods.

The British Standards Institution (BSI) has implemented "Methods for Test for Penetration of Erythemally Weighted Solar Ultraviolet Radiation Through Clothing Fabrics." Additional information on this test method could not be obtained without purchasing it. In addition, The International Test Association for Applied UV Protection and the German Hohenstein Institute developed UV Standard 801 to examine the ultraviolet protection of textiles both during the actual use of the item and after stretching, wetting, abrading or laundering of the textile item. Similar to the AATCC method, UV Standard 801 supplies a factor specified for the ultraviolet protection of the fabric after it is tested. As with the British Standards Institution, a detailed description of the test is available, at a cost, for public viewing. It is important to note that the AATCC method is based on the Australian/New Zealand test, AS/NZS 4399:1996, which was the first test to be developed for evaluating and classifying clothing as sun protective.

ULTRAVIOLET RADIATION

Over the past decade, concerns have been rising due to the depletion of the ozone layer and its resulting effects on the earth's surface. The stratospheric ozone layer serves as the earth's main natural protection against harmful ultraviolet radiation from the sun. Therefore, depletion of the ozone layer is of significant importance because of associated potential health risks. Scientists classify ultraviolet radiation (which is between two hundred and four hundred nanometers) into three distinct wavelength regions. These three regions are UV-A (320-400 nanometers), UV-B (290-320 nanometers), and UV-C (200-290 nanometers). The UV-C rays are completely absorbed by the atmosphere before reaching the earth and we are thus not concerned with these rays for this effort. This effort is mostly concerned with that of UV-B, which has biologically destructive wavelengths and account for 0.5% of the total ultraviolet light from the sun that reaches the earth's surface [(2)]. A wide variety of diseases and harmful health effects can result from overexposure to UV-B rays; the effects of which will be discussed in detail later in this report. Additionally, we are concerned with UV-A rays, which are estimated to account for approximately 5% of the total sunlight reaching the earth's surface[2]. An important fact is that more than 90% of the UV-B rays that reach the earth are absorbed by the skin as well as 50% of the UV-A rays, which are known to penetrate the deepest[2].

In an effort to combat these harmful health effects, scientists are working to develop such technologies that range from sunscreens to clothing to sunglasses. There have been increasing efforts to safeguard and educate the general public about the consequences of overexposure to the sun's rays and the preventative measures they can take to decrease their own risk. A prime example of this increase in awareness is that of the introduction of the standard test methods used for this effort.

DAMAGING EFFECTS OF ULTRAVIOLET RADIATION

There are a number of health risks that result from overexposure to the sun or ultraviolet light. While such health problems do not usually occur until adulthood, it is believed that the amount of exposure to the sun as a child greatly impacts an individual's probability of developing a sun-related disease later in life. In fact, reducing the amount of such exposure as a child can significantly reduce such health hazards later in life.

Skin Cancer

Annually it is estimated that almost one million people in the United States are diagnosed with some form of skin cancer, including both melanoma and non-melanoma. Melanoma skin cancer arises in the melanocytes, which are the skin cells that produce pigment. Non-melanoma skin cancer arises in the basal cells, which are found in the lower part or base of the outer layer of skin, or the squamous cells, that cover the internal and external surfaces of the body. It is estimated that in 1999 the death rate from non-melanoma cancer in the United States was 1,900 while the death rate of melanoma was approximately 7,300[3]. While exposure to ultraviolet radiation isn't the only factor contributing to the development of skin cancer, it is one of the main attributes. In fact, it is estimated that every 1% drop in the stratospheric ozone will increase the rate of skin cancer by as much as 2-3%[4]. Skin cancer accounts for approximately 40% of all new cancer cases reported in the United States each year[5]. Additionally, it is reported that

over 90% of melanoma, basal cell carcinoma, and squamous cell carcinoma cases are due to exposure to sunlight[5].

Statistically, it has been reported that there are higher incidences of skin cancer in areas that have a closer proximity to the equator. These rates of skin cancer are 10 times higher in whites than in blacks due to differences in the pigmentation of the skin[5]. In particular, in whites, the incidences of skin cancer tend to be highest among people with red hair and lowest among people with black hair[5]. Incidence rates for blonde-haired people tend to fall in the middle of the range. Additionally, those who burn easily are at a greater risk of developing skin cancer than those who tan when exposed to the sun[5].

Photoaging (Premature Aging)

Exposure to the sun causes premature aging[3] of the skin. Chronological aging occurs as one gets older. However, this process can be accelerated as a result of regular sunbathing or outdoor activity. Photoaging can occur in individuals before they reach age 30, whereas chronological aging doesn't usually begin until after 40 years of age. Some indicators of photoaging include freckles, fine wrinkles and the dilation of capillaries. Furthermore, skin that ages prematurely often develops irregular pigmentation, sometimes referred to as liver spots.

Cataracts and Eye Disorders

Ultraviolet exposure is also linked to cataracts[5], which can ultimately lead to blindness. In addition, there are a number of other eye disorders that result from exposure to the sun, which range from corneal sunburn to growths on the outer surfaces of the eye. Such disorders usually develop after extended exposure to ultraviolet rays.

Immune System Damage

The human skin is one of the main defense mechanisms for the human body. Thus, damage to the skin can be harmful to the body and affect its ability to fight off disease or infection[5].

ULTRAVIOLET PROTECTION OF CLOTHING

Sun protective is a term that is being applied more and more frequently to clothing. While all fabrics offer some degree of protection from the sun, there are a number of construction techniques that can greatly influence the ultraviolet protection level of textiles and thus give more favorable ratings during testing. The characteristics believed to affect resistance to ultraviolet radiation are described below. The American Medical Center (AMC) Cancer Research Center has designated clothing with UPF ratings of 15 to 50+ as being sun protective[1]. This determination is based on UPF ratings derived from the AATCC and ASTM test methods. In addition, they caution that only clothing which covers a significant portion of the body, such as to the neck, elbows, and knees, can be rated as sun protective.

Type of Fiber

Different fiber types[6,8] provide different levels of ultraviolet protection. For example,

cotton, wool and silk have innate characteristics that cause them to be better absorbers of ultraviolet rays[7].

Fabric Stretch

The less stretch[6,8] a fabric has, the more likely it is to provide a greater degree of protection from ultraviolet rays. Knitted fabrics, in particular, are more likely to allow for the penetration of the sun's rays than woven fabrics. Tight fitting fabrics provide less protection than more relaxed, loose-fitting garments. Exceptions to these are fabrics made from Lycra fibers, which are consistently rated highly for protection against ultraviolet radiation.

Fabric Weave and Fabric Cover

The tighter the weave[6,8] of a fabric, i.e. the less space between the yarns, the more protection it will provide the wearer from ultraviolet rays. While some UV light may pass through the yarns themselves, some will pass through the holes. The fabric cover refers to the percentage of the total area of the fabric that is taken up by both the warp and filling yarns. Thus, the greater percentage that fabric cover takes up, the greater the amount of protection the fabric will provide against ultraviolet radiation.

As stated by Collier and Epps[9], cover factor is determined by using the following formula:

$K_{fabric} = K_W + K_F,$ Equation 1
where K_W (or K_f) = N/square root of CC
where K = cover factor
N= fabric count
CC=cotton count
w = warp
f = filling

In order to reach the minimum UPF of 15, textiles must have a cover factor that is at least 93%. However, once the cover factor reaches 95% there will be little change in the UPF[6]. Ideally, yarns should be opaque to ultraviolet light, which will aid in decreasing the amount of ultraviolet transmission through the fabric.

Fabric Porosity

There are various suggestions on the recommended levels of fabric porosity, or the volume of air within the boundaries of the material, depending on the end-use of the fabric. As stated by Collier and Epps[9], fabric porosity is calculated using the formula:

$P = 100\,(AT - W/D)/AT$ Equation 2
where P = porosity of the fabric
A = area of the fabric specimen in cm^2
T = thickness of fabric specimen in cm
W = weight of fabric specimen in grams
D = specific gravity or density of fiber in g/cm^3.

For example, it is recommended that fabric porosity of UV protective textiles should not be less than 1.5% in the stretched state[10]. Some believe that fabric porosity for undyed, woven fabrics is the best indicator of a fabric's ultraviolet protection levels[11]. It is unclear how different fabric porosity is from fabric cover. The two are sometimes used interchangeably.

Fabric Color

Generally, darker colored fabrics[6,8] allow less penetration of ultraviolet rays than lighter colored fabrics because darker dyes tend to absorb ultraviolet radiation. However, the results depend on how the dyes are absorbed in the ultraviolet region. Some fibers have inherent qualities that allow them to be better UV absorbers. An example of this is natural cotton. It is a better UV absorber than a white cotton and viscose. However, studies indicate color may not be a reliable indicator of the amount of UV protection the fabric provides (12). It is important to note that different dyes may have different levels of ultraviolet protection, thus ratings may vary from supplier to supplier.

Fabric Weight

Thicker and heavier fabrics[8] afford a greater degree of protection than thinner fabrics, providing that both fabrics are constructed with the same weave.

Water

The presence of water[6,8] also impacts the ability of a fabric to protect the wearer against the sun. The fabric scatters light less when wet, causing it to be more transparent. Such effects of wetness depend on the fiber used, how absorbent it is, and the fabric structure. Structure is particularly important because some fabric structures allow for more interstitial water. Cotton, wool, and silk are very absorbent fibers which may cause a decrease in their protective qualities whereas synthetic materials are nonabsorbent and repel water, thus increasing their protective qualities. Overall, wetness tends to reduce the effectiveness of protection against ultraviolet radiation, but it has been documented to increase effectiveness in some instances.

Use of Fabric

Stretching or fading during use and laundering can affect the level of protection provided by a fiber[6,8]. While shrinkage may initially help to counteract such effects, extended wear will decrease UPF ratings because it reduces weight and thickness. Laundering has actually been found to increase the UPF levels, which can be attributed to fluorescent whitening agents commonly found in detergents. Fluorescent whitening agents tend to absorb UV light, thus contributing to their overall effectiveness in increasing UPF levels.

Additives

Certain additives[6,8] and finishes, such as Rayosan®, which is marketed by Sandoz, and fluorescent whitening agents, Tinofast CEL, and Tinofast PS, can be added to fabrics to increase ultraviolet protection. Textile scientists have also found that a combination of

0.5% micro titanium dioxide and 0.4% titanium dioxide can improve the scattering of ultraviolet radiation[10]. Chemical treatments and resin coatings are known to increase the UPF, but these can also decrease with wear and sometimes may affect the hand of the fabric. Presumably, delustered fibers have better protection against ultraviolet radiation.

DETERMINING THE ULTRAVIOLET PROTECTION FACTOR (UPF)

The AATCC developed a rating system in order to determine the ultraviolet protection factor for textiles. The rating system is determined as a result of the total ultraviolet transmission through the fabric and the skin's response to the rays. First, the amount of ultraviolet transmission of the fabric must be calculated by measuring the UV spectral transmittance of the fabric using a spectrophotometer. Spectral transmittance refers to the amount of ultraviolet radiation that penetrates the fabric and fibers at each wavelength. For the purposes of this effort, the spectral transmittance is measured only for the UV-A and UV-B wavelengths, i.e. 290-400 nanometers. Data is gathered for the spectral transmittance of each specimen at a minimum of three different angles. The first UV transmission measurement should be taken in one direction with the second measurement taken at 0.79 rad (45 degrees) to the first and the third taken at 0.79 rad (45 degrees) to the second[13]. Then, this data at each wavelength is multiplied by the solar irradiance at the same wavelength and by a factor representing the effectiveness of that wavelength in causing erythema[14]. The final UPF value is calculated by comparing the erythemally weighted total solar UV for no fabric to that with fabric present. Based on the lowest UPF level measured, the fabric is then assigned a UPF factor.

The UPF factors allow for people to identify the effectiveness of a fabric to inhibit ultraviolet radiation and range from 15 to 50. The higher the UPF level, the greater the protection provided by the fabric. The ASTM procedure has been developed to simulate ageing of the fabric, which is applied before the AATCC test is conducted, thus allowing for a measure of the UPF level after wear, as stretch or other factors may have a significant impact on the UPF level of the fabric. Table 1 shows the various classification categories, UPF ranges, labeling values and the percent of ultraviolet radiation blocked.

Table 1: UPF Classification Categories

Classification Category	**UPF Range for Classification Category**	**Allowable UPF values for labeling purposes**	**Approximate Average % UV Blocked** (Use your product's actual percentages for labeling.)
Good UV Protection	15-24	15 and 20	93.3% - 95.8%
Very Good UV Protection	25-39	25, 30, 35	96.0% - 97.4%
Excellent UV Protection	40-50+	40, 45 and 50+	97.5% - 98%

*** This table can be found at http://www.aspa.amc.org/aspa6.htm*

INTERNATIONAL UV TESTING LABORATORIES

The tests were conducted at the International UV Testing Laboratories in Auburn, Alabama. Natick Soldier Center was unable to conduct the necessary tests because of a discrepancy in the required testing instruments. Standard spectrophotometers measure the reflectance of the fabrics. However, our test methods required the measure of the transmission of such fabrics. Therefore, it was determined that the equipment at Natick did not have the appropriate capabilities to suit our needs. Additionally, the University of Rhode Island (URI) also did not have an ultraviolet analyzer, such as the Labsphere® UV-1000F, at the time of testing. Since the testing has taken place, both Natick and URI have received the appropriate measuring devices to conduct such tests in the future.

TESTING EQUIPMENT

The following is a description of the equipment used to perform the AATCC and ASTM procedures.

Labsphere UV-1000F Ultraviolet Analyzer

This instrument measures the transmittance of ultraviolet radiation-ranging from 250-450 nanometers-through the fabric. From this measurement, the sun protection factor (SPF) and UPF were calculated using solar irradiance and erythemal effectiveness data.

Atlas Ci 3000 Xenon Arc Weatherometer

This was used for light exposure as per ASTM D 6544. Fabric samples were subjected to 100 AFUs of xenon light exposure. This device allowed for the closest simulation of ultraviolet rays.

AATCC Approved Washers and Dryers

The AATCC approved washers and dryers were used for laundering the fabric samples. As per AATCC 135, all samples were machine washed in the permanent press cycle with AATCC Standard Detergent 1993. The samples were then tumble-dried at low heat with a cool down cycle. As per ASTM D 6544, fabric samples were subjected to 40 launderings under such conditions, which simulated approximately two years of use. Listings of current AATCC approved washers and dryers can be received by contacting AATCC, P.O. Box 12215, Research Triangle Park, NC 27709; telephone: 919-549-8141; fax: 919-549-8933; e-mail: orders@aatcc.org.

MILITARY FABRICS TESTED

Four military fabrics were tested by the International UV Testing Laboratory to determine their ultraviolet protection factors. The fabrics were selected because they are worn directly against the skin, usually with no outer garments, and because of their frequency of use in areas where soldiers are most likely to be exposed to the sun and, thus, ultraviolet radiation. Listed below are the fabrics tested and their specifications.

Desert Battledress Uniform Fabric, Desert Printed, Class 3 – MIL-C-44436

This fabric is a wind-resistant poplin that is made of a nylon/cotton blend. It has been dyed and overprinted with a Desert camouflage pattern using Light Tan 492, Light Khaki 494 and Light Brown 493. The fabric specification indicates that the fabric weight must be between 6.0 –7.0 ounces per square yard and must have a minimum of 104 warp yarns per inch and 52 filling yarns per inch.

Hot Weather Battledress Uniform Fabric, Woodland Printed, Class 1 – MIL-C-44436

This fabric is also wind-resistant poplin made of a nylon/cotton blend. It has been dyed and overprinted with a Woodland camouflage pattern using Light Green 354, Dark Green 355, Brown 356, and Black 357. The fabric specification indicates that the fabric weight must be between 6.0 –7.0 ounces per square yard and must have a minimum of 104 warp yarns per inch and 52 filling yarns per inch.

Temperate Battledress Uniform Fabric, Woodland Printed, Class 1 – MIL-C-44031

This fabric is a cotton/nylon blend with a twill weave. It has been dyed and overprinted with a Woodland camouflage pattern using Light Green 354, Dark Green 355, Brown 356, and Black 357. The fabric specification indicates that the fabric weight must be a minimum of 6.8 ounces per square yard. It must contain a minimum of 86 warp yarns per inch and 54 filling yarns per inch.

Air Crew Battledress Uniform Fabric, Woodland Printed, Type II – MIL-C-83429

This fabric is a plain weave aramid blend. It has been dyed and overprinted with a Woodland camouflage pattern using Light Green 354, Dark Green 355, Brown 356, and Black 357. The fabric specification indicates that the weight must be between 4.7 – 6.0 ounces per square yard. It must contain 69 warp yarns per inch and 44 filling yarns per inch.

DATA AND FINDINGS

The data indicates that the four military fabrics tested rated highly for ultraviolet protection. Table 2 shows the results and the UPF ratings for each fabric.

Table 2: UV Transmittance and UPF values of Four Camouflage Fabrics, as tested by International UV Testing Laboratories

FABRIC	COLOR	COLOR #	STATUS*	UPF	%UVA	%UVB	Label UPF	ASTM D6544 Label
MIL-C-44436	LT TAN	492	INITIAL	240	1.35	0.31	50+	Excellent UV Protection
BDU	LT TAN	492	40W+100L	414	0.76	0.17	50+	Excellent UV Protection
DESERT	LTBROWN	493	INITIAL	1440	0.16	0.06	50+	Excellent UV Protection
CLASS 3	LTBROWN	493	40W+100L	2035	0.09	0.05	50+	Excellent UV Protection
	KHAKI	494	INITIAL	413	0.56	0.19	50+	Excellent UV Protection
	KHAKI	494	40W+100L	687	0.31	0.12	50+	Excellent UV Protection
MIL-C-44436	LT GREEN	354	INITIAL	856	0.23	0.1	50+	Excellent UV Protection
WOODLAND	LT GREEN	354	40W+100L	920	0.17	0.1	50+	Excellent UV Protection
CLASS 1	DR GREEN	355	INITIAL	1484	0.1	0.07	50+	Excellent UV Protection
	DR GREEN	355	40W+100L	1698	0.07	0.06	50+	Excellent UV Protection
	BROWN	356	INITIAL	1498	0.08	0.07	50+	Excellent UV Protection
	BROWN	356	40W+100L	2049	0.05	0.05	50+	Excellent UV Protection
	BLACK	357	INITIAL	16597	0.01	0.01	50+	Excellent UV Protection
	BLACK	357	40W+100L	6262	0.02	0.02	50+	Excellent UV Protection
MIL-C-44031	LT GREEN	354	INITIAL	576	0.33	0.15	50+	Excellent UV Protection
WOODLAND	LT GREEN	354	40W+100L	666	0.26	0.13	50+	Excellent UV Protection
CLASS 1	DR GREEN	355	INITIAL	884	0.17	0.11	50+	Excellent UV Protection
	DR GREEN	355	40W+100L	1152	0.12	0.08	50+	Excellent UV Protection
	BROWN	356	INITIAL	977	0.13	0.1	50+	Excellent UV Protection
	BROWN	356	40W+100L	1328	0.09	0.08	50+	Excellent UV Protection
	BLACK	357	INITIAL	2237	0.06	0.04	50+	Excellent UV Protection
	BLACK	357	40W+100L	2324	0.05	0.04	50+	Excellent UV Protection
MIL-C-83429	LT GREEN	354	INITIAL	40	2.77	2.43	35	Very Good UV Protection
WOODLAND	LT GREEN	354	40W+100L	61	1.82	1.63	50+	Excellent UV Protection
TYPE II	DR GREEN	355	INITIAL	42	2.49	2.33	40	Excellent UV Protection
	DR GREEN	355	40W+100L	79	1.35	1.26	50+	Excellent UV Protection
	BROWN	356	INITIAL	43	2.44	2.32	35	Very Good UV Protection
	BROWN	356	40W+100L	71	1.47	1.4	50+	Excellent UV Protection
	BLACK	357	INITIAL	47	2.22	2.12	40	Excellent UV Protection
	BLACK	357	40W+100L	72	1.47	1.4	50+	Excellent UV Protection

*40W=40 Wash Cycles
100L=100 AATCC Fading Units

CONCLUSIONS

The data indicates that initially, each individual color of each fabric demonstrated "Excellent" UV protection, with the exception of Light Green 354 and Brown 356 of MIL-C-83429, which were "Very Good".

After simulated wear representing two years, every color of each fabric demonstrated "Excellent" UV Protection, which is the highest protective rating.

This document reports research undertaken at the U.S. Army Soldier and Biological Chemical Command, Soldier Systems Center, and has been assigned No. NATICK/TR-02/006 in a series of reports approved for publication.

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APPENDIX

UV TESTING LOCATIONS

Auburn University
International UV Testing Laboratories
324 South Cedarbrook Drive
Auburn, AL 36830
Office: (334) 844-1330
Fax: (344) 844-1340
Contact: Lewis Slaten, Ph.D., slatebl@auburn.edu,
http://www.auburn.edu/~slatebl/index2.html

Cal Poly State University
Textile Research and Testing Laboratory
San Luis Obispo, CA 93407
Office : (805) 756-2470
Fax : (805) 756-5753
Contact : Lezlie Labhard Ph.D.

DSET Laboratories
45601 North 47th Avenue
Phoenix, AZ 85087-7042
Office: (800) 255-3738
Fax: (623) 465-9409
Contact: Tom Anderson

ICS Laboratories
1072 Industrial Parkway
North Brunswick, OH 44212
Office: (330) 220-0516
Fax: (330) 220-0516
Contact: Keith Whitten, www.icslabs.com

Merchandise Testing Laboratories
244 Liberty Street
Brockton, MA 02401
Office: (508) 580-8353
Fax: (508) 580-2669
Contact: Melissa Strong, Melissa_strong@mtlusa.com

Mile High Textiles
2030 South Dahlia
Denver, CO 80222
Office: (303) 692-8939
Fax: (303) 692-8939
Contact: Andy Franklin

Rapid Precision Testing Laboratories
P.O. Box 1342
Cordova, TN 38088-1342
Office: (901) 386-0175
Fax: (901) 386-7218
Contact: Robert M. Sayre, Ph.D., http://members.aol.com/RPTL

STR – Specialized Testing Resources
10 Water Street
Enfield, CT 06082-4899
Office: (860) 749-8371
Fax: (860) 749-8234
Contact: Patricia Laughlan

Suncare Research Laboratories, LLC
740 East Brookhaven Circle
Memphis, TN 38117
Office: (901) 438-5227
Contact: Joe Stanfield, www.suncarelab.com

University of Nebraska
Textile Testing Service
Department of Textiles
Lincoln, NE 68583
Phone: (402) 472-6342
Fax: (402) 472-0640
Contact: Patricia Crews, Ph.D.

University of Rhode Island
Department of Textiles, Fashion Merchandising and Design
55 Lower College Road
Kingston, RI 02881
Phone : 401-874-2276
Fax : 401-874-2581
Contact : Dr. Martin Bide, mbide@uri.edu

Vartest Laboratories Inc.
Textile Testing Service Division
19 West 36th Street
New York, NY 10018
Office: (212) 947-8391
Fax: (212) 947-8719
Contact: Adam Varley

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GLOSSARY

Basal Cell Carcinoma – a type of skin cancer that arises from the basal cells, small round cells found in the lower part or base of the epidermis, the outer layer of the skin (15).

Cancer – a term for diseases in which abnormal cells divide without control. Cancer cells can invade nearby tissues and can spread through the bloodstream and lymphatic system to other parts of the body (15).

Carcinoma – cancer that begins in the skin or in tissues that line or cover internal organs (15).

Dermis – the lower or inner layer of the two main layers of tissue that make up the skin (15).

Epidermis – The upper or outer layer of the two main layers of tissue that make up the skin (15).

Erythema – abnormal redness of the skin (sunburn) due to capillary congestion (inflammation) (13).

Melanin – the substance that gives skin its color (15).

Melanocytes – cells in the skin that produce and contain the pigment called melanin (15).

Melanoma – a form of skin cancer that arises in melanocytes (15).

Nanometer – a measure of wavelength. One nanometer is equal to 10^{-9} meters. It is used to differentiate portions of the magnetic spectrum. Visible light has wavelengths between 400 and 700 nanometers.

Non-Melanoma Skin Cancer – skin cancer that arises in basal cells or squamous cells but not in melanocytes (15).

Percent UV Blocking – 100 minus the UV transmission (13).

Spectrophotometer – instrument used to set color standards by sensing reflected color of a specimen at several individual wavelengths within the visible spectrum (9).

Squamous Cell Carcinoma – cancer that begins in squamous cells (15).

Squamous Cells – flat cells that look like fish scales under a microscope. These cells cover internal and external surfaces of the body (15).

Sun Protective Clothing – any garment that provides adequate protection from the sun; clothing must have a UPF value of 15 to 50+ which block 93-98% of UV radiation and cover or shade sufficient skin to protect a person from the damaging rays of the sun. The ASTM defines sun protective clothing as any apparel product, such as shirts, pants, hats and skirts, that is manufactured or treated in such a way that it provides added protection from the damaging effects of the sun (16).

Sun Protection Factor (SPF) – scale for rating the level of sunburn protection in sunscreen products (15).

Sunscreen – a substance that helps protect the skin from the sun's harmful rays. Sunscreens reflect, absorb, and scatter both UVA and UVB radiation. Using lotions, creams, or gels that contain sunscreens can help protect the skin from premature aging and damage that may lead to skin cancer (15).

Ultraviolet Protection Factor (UPF) – the ratio of the average effective ultraviolet radiation (UV-R) irradiance transmitted and calculated through the air, to the average effective UV-R irradiance transmitted and calculated through fabric (13).

Ultraviolet Radiation (UV-R) – invisible rays that are part of the energy that comes from the sun; UV radiation can damage the skin and cause melanoma and other types of skin cancer (15).

UVA Rays – long wavelength ultraviolet rays from the sun; UVA rays are the "aging" rays in the UV spectrum; UVA radiation ranges from 320 to 400 nanometers in wavelength.

UVB Rays – medium wavelength ultraviolet rays from the sun; UVB rays are the "burning" rays in the UV spectrum; UVB radiation ranges from 280 to 320 nanometers in wavelength.

Wavelength – the distance between successive crests of electromagnetic wave passing through a given material (17).